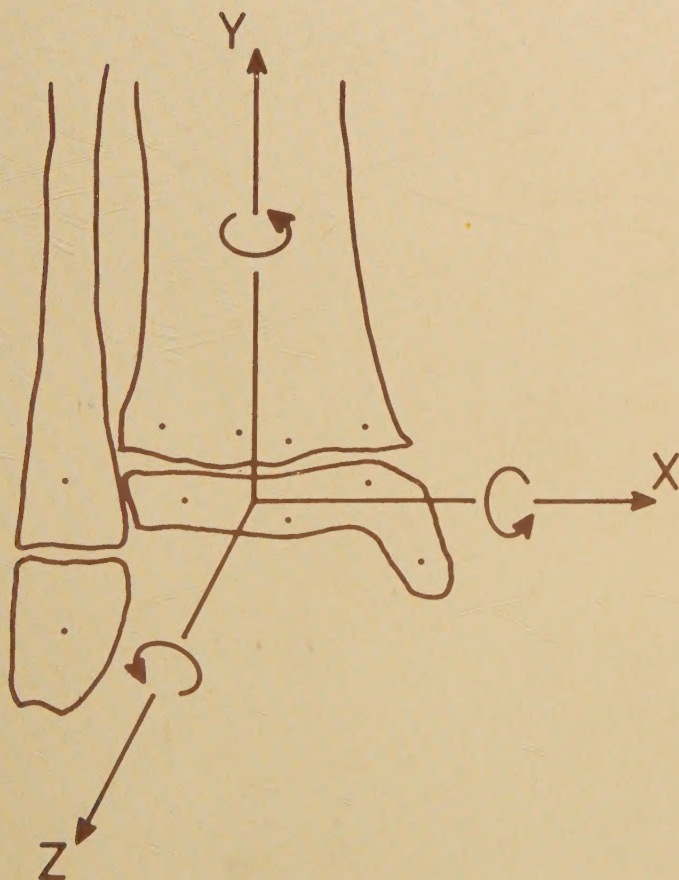


Ankle Fractures in Children

Incidence, Fracture Anatomy, and Treatment with
Special Reference to Post-traumatic Growth Patterns

Johan Kärrholm



Lund 1982



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To my wife and children

The present summary is based on the following papers which will be referred to by their roman numerals:

- I. Kärrholm, J., Hansson, L.I. & Svensson, K.: Incidence of tibio-fibular shaft and ankle fractures in children. J. Pediatr. Orthop. In press.
- II. Kärrholm, J., Hansson, L.I. & Laurin, S.: Supination-eversion injuries of the ankle in children: A retrospective study of radiographic classification and treatment. J. Pediatr. Orthop. 2, 147-159, 1982
- III. Kärrholm, J., Hansson, L.I. & Laurin, S.: Computed tomography of intra-articular supination-eversion fractures of the ankle in adolescents. J. Pediatr. Orthop. 1, 181-187, 1981
- IV. Kärrholm, J., Hansson, L.I. & Selvik, G.: Roentgen stereophotogrammetric analysis of growth pattern after supination-eversion ankle injuries in children. J. Pediatr. Orthop. 2, 25-37, 1982
- V. Kärrholm, J., Hansson, L.I. & Laurin, S.: Supination-adduction injuries of the ankle in children - Radiographical classification and treatment. Arch. Orthop. Traumat. Surg. Submitted for publication
- VI. Kärrholm, J., Hansson, L.I. & Selvik, G.: Roentgen stereophotogrammetric analysis of growth pattern after supination-adduction ankle injuries in children. J. Pediatr. Orthop. In press
- VII. Kärrholm, J., Hansson, L.I., Laurin, S. & Selvik, G.: Post-traumatic growth disturbance of the ankle treated by the Langenskiöld procedure. Evaluation by radiography, roentgen stereophotogrammetry, scintimetry, and histology. Case report. J. Pediatr. Orthop. Submitted for publication
- VIII. Kärrholm, J., Hansson, L.I. & Laurin, S.: Pronation injuries of the ankle in children - A retrospective study of radiographical classification and treatment. Acta Orthop. Scand. In press.
- IX. Kärrholm, J., Hansson, L.I. & Selvik, G.: Roentgen stereophotogrammetric analysis of growth pattern after pronation ankle injuries in children. Acta Orthop. Scand. In press

- X. Kärrholm, J., Hansson, L.I. & Selvik, G.: Roentgen stereo-photogrammetric study of growth pattern after fracture through tibial shaft, ankle, and heel. Arch. Orthop. Traumat. Surg. 99,253-258, 1982
- XI. Kärrholm, J., Hansson, L.I. & Svensson K.: Prediction of growth pattern after ankle fractures in children. J. Pediatr. Orthop.
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Chapter I

INTRODUCTION

Clinical problems associated with ankle fractures in children have been discussed for more than a century. The relative frequencies have been determined in several studies, and growth plate injury and joint incongruity have been found to be of prognostic importance. Anatomical and traumatological classifications have been presented to predict long-term prognosis concerning growth problems and joint development, and to facilitate the treatment.

Although the relative frequency of ankle fractures in children has been estimated in several studies, the incidence of these in a defined population has not been determined.

Anatomical classifications have been proved valuable, but they have been questioned concerning their accuracy in predicting the prognosis for future growth; and moreover, they do not include all types of fractures.

Traumatological classifications have manifested great variability. However, Gerner-Smidt (1963) presented a comprehensive traumatological classification based on experimental work and a clinical material of 492 cases. Of the fracture types experimentally produced, the supination-eversion injury, recognized in more than 100 cases, was a new concept that was only vaguely described in earlier materials.

Marmor (1970) described a case of the intra-articular type as "an unusual fracture of the tibial epiphysis". Later the fracture was given the name triplane fracture by Lynn (1972). During the last decade, the largest material presented included 15 cases (Cooperman et al. 1978).

The anatomy of the triplane fracture was further investigated radiographically; delineating the fracture anatomy was facilitated by the introduction of computed tomography (Cooperman et al. 1978, Chalmers et al. 1981, von Laer 1981, 1982). Up to now, 4 different fracture types

have been described. The coexistence of several fracture patterns has not always been recognized.

Radiographic registration of the effect of trauma on longitudinal bone growth was earlier performed using orthoroentgenographic examinations (Hedström 1969, Spiegel et al. 1978, Reynolds 1981). The whole bone was measured, not allowing detailed growth registration from one of its ends unless markers were implanted; and measurements during short time periods, such as months, were crude due to the error of method (Hedström 1969). Other methods, such as tetracycline labelling (Hansson 1967), were not appropriate for registration in man. Thus, the initial growth pattern after physeal fractures of the ankle during intervals from one to several months after fracture was not known because of limitations of earlier methods.

However, less than 10 years ago Selvik (1974) introduced his roentgen stereophotogrammetric method, which enables high-accuracy measurements of longitudinal growth. The experimental and clinical applicability of this method for growth registrations was investigated by Aronson (1976).

In conclusion, several aspects of ankle fractures in children have been investigated, but the results have not been unequivocal. In order to enlarge the knowledge in this field, the present investigation was initiated (I-XI).

Chapter II

REVIEW OF THE LITERATURE

2.1. Historical Notes

According to Rognetta (1834) and Poland (1898), it is probable that fractures involving the growth plate were known to Hippocrates and Galenos (Ingrassias).

During the 17th century, solitary cases were described by Severinius (1632) and Parey (1634). Severinius (1632) described deformities resulting from physeal fractures.

Reichel (1759) was probably the first to distinguish between traumatic physeal fractures and separations due to disease, but according to Poland (1898) the authenticity of the specimens presented was uncertain.

During the 19th century, an increasing number of physeal fractures were described (for review, see Poland 1898, 1965), but the existence of these injuries were not generally accepted until the end of the century (Hutchinson 1885).

Simultaneously with the increasing interest of the genetic production of ankle fractures in the adult - as manifested in several experimental studies and observations during the 19th century (Dupuytren 1836, Maisonneuve 1840, Malgaigne 1847, Hugier 1848) - physeal fractures were experimentally produced and/or described (Gueretin 1837, Gurtl 1862, Foucher 1860, 1863, Ollier 1881, Bruns 1882, Poland 1898).

2.2. Incidence

Gurtl (1862) believed that physeal fractures were rare, and sustained during delivery or late childhood. Later, Bruns (1881) presented the first large material of physeal fractures mainly collected from the literature, and he concluded that these injuries were more common than was previously believed.

Peterson and Peterson (1972) compiled 5 materials from the 19th century representing injuries diagnosed prior to the advent of roentgenography. Injuries through the distal tibia constituted 7.2% and were exceeded by physeal fractures of the distal femur, proximal humerus, distal humerus, and distal radius. Eight materials (Bowen 1915, Smith 1924, Bergenfeldt 1934, Eliason and Ferguson 1934, Compere 1935, Bisgard and Martenson 1937, Lipschultz 1937, Neer and Horwitz 1960) from the time period using roentgenography showed a higher frequency of distal tibial injuries (11%), exceeded by physeal fractures of the distal radius and the distal humerus. Physeal fractures of the distal fibula had risen from 0.8% to 9.1%. Later, physeal fractures of the distal tibia were found to be the second most common fracture type exceeded only by injuries through the distal radius (Peterson and Peterson 1972, Ogden 1981).

Gerner-Smidt (1963) compiled a material of 492 ankle injuries in children 0 to 16 years of age during a period of 15 years and could demonstrate an increasing frequency of such injuries during this period. However, there is no study reporting the incidence of physeal fractures through the distal tibia and fibula in a defined population.

2.3. Anatomical Classification

Foucher (1860, 1963) noted that physeal fractures were easily produced by bending combined with rotation. Anatomically, 3 fracture types were described: fracture through the uncalcified part of the growth plate, through the calcified part of the growth plate, and through the metaphysis close to the growth plate. On the basis of the prognosis, he stressed the importance of separating intra- from extra-articular injuries.

The anatomical appearance of physeal fractures was further studied by Voigt (1878), Ollier (1881), Bruns (1881), and Poland (1898). Most commonly, the fractures were assumed to have passed through the metaphyseal side of the growth plate. Bruns (1881) and Poland (1898) separated pure physeal separation and physeal separation with a metaphyseal fragment of varying size. Poland, in addition, described 2 types of epiphyseal fractures with complete and incomplete physeal separation, but he regarded these injuries as being very rare.

The anatomical appearance of physeal fractures constituted a basis for later classifications presented by Bergenfeldt (1934), Aitken (1936), Salter and Harris (1963), and Ogden (1981).

Bochut (1867) adopted the conclusions of Foucher (1860) and was probably the first to report a varus deformity after an ankle fracture in a child. Later several cases were described (Owen 1891, Brodie 1896, Poland 1898) and demonstrated radiographically (McFarland 1931, Baldrian 1933, van Assen 1934, Compere 1935).

McFarland (1931) focused the interest on the fracture type responsible for this deformity, and believed that the fracture was produced by adduction.

Bergenfeldt (1934) was probably the first to re-examine an unselected material of ankle fractures in children. His classification was used by Giuliani (1952), who found a high frequency of deformity in a selected material. Compere (1935) reported deformities in 6 out of 6 cases, whereas Eliason and Furguson (1934) and Lipschultz (1937) found no complications in small materials.

The anatomical classification by Aitken (1936) was used by several authors (Dotter and Mc Holick 1953, Suessenbach and Weber 1970, Boissevain and Raaymakers 1979). They reported a varying degree of complications (5/40 - 6/28). Ehlers and Eberlein (1946), Gall (1958), and Beck and Engler (1964) presented their own classifications, but in none of the materials did the number of ankle fractures exceed 38 cases.

Bartl (1957) presented a material of 232 fractures that was classified anatomically into 4 types. Follow-up was performed in 54 cases of which 8 showed a deformity. Bartl concluded that an exact reduction is necessary to obtain a favourable result.

Spiegel et al. (1978) classified 237 cases anatomically according to Salter and Harris (1963), but separated Type II injuries due to various trauma types and also separated Type III injuries into different groups. Twenty-six cases with complications of 184 fractures were found, and the prognosis was correlated with the Salter-Harris classification. They

found that the Type II tibial fractures showed a higher risk of complications than did the minimally displaced Type III or IV fractures.

2.4. Traumatological Classification

Based on the study by Ashhurst and Bromer (1922), Bishop (1932) presented a traumatological classification of ankle fractures in children.

Carothers and Crenshaw (1955) modified Bishop's classification and in a material compared the different fracture types with the prognosis of individual injuries. Most commonly, deformity was found after adduction injuries.

Johnson and Fahl (1957) used a similar classification, but could not verify the finding by Carothers and Crenshaw (1955), nor did they believe that large epiphyseal displacement was of prognostic importance concerning future growth.

Gerner-Smidt (1963) presented a classification of ankle fractures in children based on the terminology introduced by Lauge-Hansen (1942). This seems to be the first classification based on an experimental investigation and applied to a large clinical material. Five fracture types were produced experimentally: supination-eversion, supination-adduction, supination-inversion, pronation-eversion, and pronation-abduction. One further fracture type, adduction-compression, was presented that was believed to be the result of axial compression trauma to the foot in the position of adduction. The total clinical material comprised 492 cases with fractures and ligamentous detachment. Of these, 408 cases were re-examined. The complications reported were associated with a defectively healed ligamentous injury, "periarthrosis" affecting the syndesmosis, deformity, osteo-arthritis, besides solitary cases of pseudoarthrosis, osteochondritis, and loose body of the ankle joint. Contrary to the findings of Carothers and Crenshaw (1955), the largest frequency of problems were found after pronation-eversion injuries.

Diaz and Tachdijan (1978) modified the classification of Carothers and Crenshaw and also added the position of the foot during the trauma to the direction of the force. They described 4 fracture types exclud-

ing the Tillaux and triplane fracture. This classification showed similarities to that of Gerner-Smidt, but the supination-eversion injuries were separated into different trauma types, and some fracture types were not described.

2.5. Computed Tomography

Computed tomography of the intra-articular supination-eversion fracture type was first published by Cooperman et al. (1978). They demonstrated a CT-scan at the metaphyseal level and conventional tomograms of the epiphyseal area. Only two-fragment fractures were found, and all fractures were of triplane type. Later, von Laer (1981) described 2 fractures interpreted as composed of 2 fragments, and the importance of a detailed examination of the epiphyseal and metaphyseal area was stressed. Later, the same author showed a three-fragment fracture (von Laer 1982). Chalmers et al. (1981) found only three-fragment fractures. CT of a Tillaux fracture was also reported by Chalmers et al. (1981) and von Laer (1981).

2.6. Treatment of Fracture

Poland (1898) treated simple separations of the ankle with closed reduction and splinting. Usually, closed reduction could be performed without difficulties. Bergenfeldt (1934), Bartl (1957), Gerner-Smidt (1963), and Spiegel et al. (1978) treated the majority of displaced fractures in large materials with closed reduction. Bartl (1957) and Böhler (1957) stressed the importance of exact reduction, whereas Aitken (1936), Carothers and Crenshaw (1955), and Johnson and Fahl (1957) did not.

The Salter-Harris classification was thought to provide guidelines for treatment: Rang (1974) stated that open reduction of Type II injuries is seldom necessary and Tachdjian (1972) held that open and repeated reduction is contraindicated. Nevertheless, Weber (1967) treated several Salter-Harris Type II ankle fractures with open reduction due to periosteal interposition.

Ankle fractures with epiphyseal involvement (Salter-Harris Types III-IV) should be treated with accurate anatomic reduction for normal

growth (Salter and Harris 1963, Suessenbach and Weber 1970, Ogden 1981) and to restore joint congruity (Spiegel et al. 1978)

Reduction should be performed early, within 1 (Rang 1969) or 2 weeks (Böhler 1957) after fracture.

Fixation should be performed with small screws (Spiegel and Mast 1980) or pins transversely across the epiphysis or the metaphysis. Fixation through the growth plate may be performed, but with pins placed along the longitudinal axis of the bone in the direction of growth (Siffert 1956).

Most authors (Blount 1955, Ehlers and Eberlein 1964, Rang 1974) recommend an immobilization of 3 to 6 weeks depending on age. Boissevain and Raaymakers (1979) recommend a fixation time of 6 to 9 weeks, Titze (1967) for 10 weeks, and Giuliani (1952) for even longer periods.

2.7. Post-traumatic Growth

Ollier (1867) noted in experimental investigations the influence of various lesions and their treatment on growth. The good prognosis of physal fractures that were reduced was attributed to the plane of cleavage having been situated in the metaphyseal region. Ollier also noted that some fracture types were followed by growth stimulation and that a considerable remodelling of displaced fractures was possible in the growing individual.

Bidder (1873) investigated the histologic appearance of the growth plate at different intervals of time after experimental trauma and observed that a bridging of fibrous tissue and bone developed between the bony epiphysis and metaphysis. These observations and/or other effects of trauma were later observed in several studies (Vogt 1878, Nové-Josserand 1893, Cornil and Coudray 1904, Nakahara 1909, Haas 1917, 1919, Ford and Key 1956, Campbell et al. 1959, Österman 1972). The effects of bony bridging of the growth plate on longitudinal growth were evaluated (Friedenberg 1957, Johnson and Southwick 1960, Nordentoft 1969, Österman 1972).

The possibility of growth stimulation after physeal fracture has been suggested in the literature (Witt 1958, Weber 1964), but was regarded as rare (Hipp 1963, Suessenbach and Weber 1970).

According to Rang (1969) significant growth disturbance follows approximately 10% of growth plate injuries. As mentioned above, the risk of deformity varies considerably according to different investigations. Bisgard and Martenson (1937) stated that the risk of growth disturbance after physeal fractures may reach 50%.

2.8. Growth Disturbance

The mechanism of developing growth disturbance after physeal injury and/or fracture has been discussed by several authors; and factors such as crushing of the growth plate (Aitken 1936, 1965, Brashear 1958, Salter and Harris 1963, Rang 1969), disturbed vascularization (Trueta and Amato 1960, Rang 1969, Tachdjian 1972), extent of displacement (Lombardo and Harvey 1977), extent of physeal injury (Barash and Siffert 1966), adequacy of reduction (Rang 1969, Suessenbach and Weber 1970, Ogden 1981), type of reduction (Bisgard 1938, Rang 1969), type of osteosynthesis (Siffert 1956, Campbell et al. 1959), secondary infection (Bergensfeldt 1934, Bisgard 1938), and time of immobilization (Giuliani 1952, Ehalt 1961), have been associated with the risk of developing a growth disturbance.

2.9. Growth Registration

Earlier investigations, mentioned above, have used conventional radiography, orthoroentgenograms, and clinical examination to evaluate the effect of trauma to the growth plates of the distal tibia and fibula with respect to growth.

Radiographic growth registrations were made earlier with teleroentgenography (Hickey 1924) and slit scanography (Millwee 1937). The orthoroentgenographic method was later developed and practised by several authors (Green et al. 1946, Goldstein and Dreisinger 1950, Taillard 1956, Goff 1960, Hedström 1969, Reynolds 1981). Langenskiöld (1981) implanted silver clips after operative resection of partial closure of growth plates allowing growth registrations from one end of the extremity and used the conventional roentgen technique.

Determination of positions in space by radiography was tried shortly after the discovery of this technique (Dennis 1897, Davidsson 1898). The development of roentgen photogrammetry proceeded slowly during the subsequent 75 years (Köhnle 1967), and during this period a few roentgen photogrammetric methods were introduced (Savara 1965, Cruikshank and Nixon 1970, Hallert 1970, Dennis 1972, Hindmarsh 1973). An important advance occurred when Selvik (1974, 1978) presented his roentgen stereophotogrammetric method, which permitted a very detailed examination of the post-traumatic growth pattern in children. The roentgenphotogrammetric method has been used by Aronson (1976), Olsson et al. (1976, 1977), Rune et al. (1977, 1980), Hansson et al. (1978), Baldursson et al. (1979), documenting its value as a high-precision instrument for determining movements between different segments of the skeleton. Aronson (1976) studied the growth in the distal fibula in children with various diseases, and the post-traumatic growth pattern after physeal injuries about the knee has been registered by Bylander et al. (1981a).

2.10 Treatment of Deformity

Surgical correction of growth deformity of the ankle was described by Ollier (1891). Rose (1888) treated the varus deformity by resection of the fibula. Poland (1898) found this operation insufficient and added an osteotomy of the distal tibia. Later on, osteotomy became the treatment of choice of the varus deformity (McFarland 1931, Baldrian 1932, van Assen 1934, Gill and Abbott 1941). Langenskiöld (1967b) recommended Phemister physeodesis of the distal fibula; in some cases also of the distal tibia. Physeodesis of the distal fibula after an abduction injury was reported by Oh et al. (1974).

Surgical resection of bony bridges and fat interposition was introduced by Langenskiöld (1967a) in order to restore growth. Several successfully treated patients were presented (Langenskiöld 1981), also with the use of methyl-metacrylate (Mallet 1975) or sheet Silastic and Gelfoam (Peterson 1980) as interpositional material. Distraction-physiolysis according to Ilizarov have proved valuable for treatment of deformity about the knee (Franke 1980), and might also be a therapeutic possibility for ankle deformity.

Chapter III

PURPOSE OF INVESTIGATION

This investigation was based on a retrospective and a prospective material.

Retrospective material was used:

1. To evaluate the incidence of ankle fractures and tibiofibular shaft fractures in a defined population of children 0 to 18 years of age.
2. To study the radiographic anatomy of ankle fractures in children.
3. To apply and to compare the traumatological classification by Gerner-Smidt to the anatomical classification by Salter and Harris.
4. To study the types and effects of treatment used in ankle fractures.

Prospective material was used:

1. To evaluate the anatomy of intra-articular supination-eversion injuries with computed tomography (CT).
2. To evaluate the post-traumatic growth pattern by roentgen stereophotogrammetry.
3. To investigate factors of importance for predicting the post-traumatic growth pattern.
4. To study the growth pattern after the Langenskiöld operation and the morphology of the growth plate with a post-traumatic growth disturbance.

Chapter IV

MATERIALS AND METHODS

4.1. Retrospective Material (I, II, V, VIII)

Children and adolescents aged 0 to 18 years with tibiofibular shaft and/or ankle fractures and treated as out- and/or in-patients at the Department of Orthopaedic Surgery, University Hospital, Lund, during the years 1971-1979 were traced using the diagnosis code register (af Ekenstam et al. 1976). Data from the case records regarding age, sex, date of injury, mechanism of injury, and treatment were collected and the radiographs were re-evaluated.

In all, there were 462 fractures of the tibiofibular shaft and 457 ankle fractures in 450 and 453 children, respectively.

4.2. Prospective Material (III, IV, VI, VII, IX, X, XI)

In 52 patients (29 boys, 23 girls) with ankle fractures and in 3 girls with ankle fractures and associated tibiofibular shaft fractures, the post-traumatic growth pattern was registered with roentgen stereophotogrammetry (Selvik 1974).

Five adolescents with intra-articular supination-eversion injuries were examined with computed tomography (Philips Tomoscan 300). Two patients, 1 with a Tillaux fracture and 1 boy with a triplane fracture combined with a fracture of the fibula, were also examined with conventional tomography. The other 3 patients, all girls, had a triplane fracture of the distal tibia.

4.3. Radiographical Classification

Tibiofibular shaft fractures (I)

Tibiofibular shaft fractures were classified according to Bauer et al. (1962), Edwards (1965), and Öennerfält (1978).

- a. Transverse fracture. The fracture formed an angle of $45-90^{\circ}$ with the long axis of the tibial or fibular shaft.
- b. Longitudinal fracture. The fracture formed an angle of less than 45° with the long axis of the tibial shaft and was represented as a spiral or long oblique fracture without involvement of the proximal or distal growth plate and/or proximal and distal tibial or fibular epiphysis.
- c. Comminuted, atypical, or unknown fracture anatomy. This group constituted mainly comminuted fractures, but also a few cases with 2 separate fractures of the tibial shaft, fractures visible only as a callus formation, and 3 fractures in 2 patients identified from the case records and of unknown radiographic appearance.
- d. Tibiofibular shaft fracture combined with ankle fracture. Fracture of the tibial shaft associated with fracture of the distal tibial growth plate or in cases with closed growth plates, engagement of the ankle joint.

Ankle fractures (I-XI)

Ankle fractures with open growth plates were classified traumatologically according to Gerner-Smidt (1963), with some modifications, and anatomically according to Salter and Harris (1963). Ankle fractures with closed growth plates, and pronation-dorsalflexion injuries were classified according to Lauge-Hansen (1942, 1953).

- a. Supination-eversion (SE)
- b. Supination-inversion (SI)
- c. Supination-adduction (SA)
- d. Adduction-compression (AC)
- e. Pronation-eversion (PE)
- f. Pronation-abduction (PA)
- g. Pronation-dorsalflexion (PD)
- h. Atypical fractures

4.4. Roentgen Stereophotogrammetric Analysis (IV, VI, VII, IX, X, XI)

For roentgen stereophotogrammetry, spherical tantalum balls, diameter 0.5 mm, were inserted (Aronson et al. 1974) through the surgical wound during general anaesthesia or more commonly percutaneously during local anaesthesia after fracture healing. The insertion was performed with the aid of fluoroscopy. Three to 5 balls were inserted on each side of the growth plate in the distal tibia on the injured side, whereas in most cases 1 ball was inserted on each side of the growth plate in the distal fibula on both sides, as well as in the distal tibia on the intact side. Minimal effects on growth by insertion of tantalum balls were registered by Aronson and Hansson (1976). The biocompatibility of tantalum balls has been demonstrated (Aronson 1976, Alberius 1982). Insertion of tantalum markers is considered to be an established and recognized method for clinical use (Rune 1980, Rune et al. 1980).

The patients were followed with roentgen stereophotogrammetry. The first examination took place 1 to 3 weeks after implantation of the markers. The next examination was performed 1 month later. Examinations were then performed at intervals of 3 to 6 months during the first year and then at intervals of 6 to 12 months if further follow-up was indicated.

At the roentgen stereophotogrammetric examination, the ankle was placed in a Plexiglas[®] calibration cage with metal markers. Biplanar technique was employed, in which 2 roentgen tubes expose the films simultaneously. The patient's body was shielded with a lead apron. The radiation dose for 1 roentgen stereophotogrammetric examination was evaluated and found rather constantly to be about 0.7 mGy for each examination. The radiation dose of a conventional X-ray examination of the ankle was found to vary between 1.3 mGy and 10 mGy depending on the technique used.

The films were evaluated in the Wild Autograph A8; a precision instrument for aerial photogrammetry. The co-ordinates for the centre of the balls were recorded, and the three-dimensional co-ordinates of the balls, and distances between the bone markers were found by computer processing. The changes in distances between the corresponding bone markers

in the epiphysis and metaphysis between 2 examinations were taken as the longitudinal growth (Aronson 1976). On the fractured side, the distances between the markers within the tibial epiphysis and metaphysis were registered to determine the stability of the markers within the bone. The method error of growth evaluation (longitudinal growth) is about 30 to 50 μm (Selvik 1974). This corresponds to about 1 μm for daily growth registered at monthly intervals.

In a separate computer program (KINEMA) for rigid-body kinematics, the metaphyseal and epiphyseal markers are modelled as rigid bodies; and movements along and about the 3 axes identified by the calibration cage are calculated for the entire epiphysis in relation to the metaphysis. The KINEMA calculation error is about 50 μm and 0.1 to 0.2° (S.D.) for translations and rotations, respectively.

On the injured side, where 4 tantalum balls were inserted on each side of the growth plate, the longitudinal growth could be calculated both as a mean value for changes of distances between metaphyseal and epiphyseal bone markers and as the translation along the longitudinal axis of the bone according to the KINEMA analysis. Both methods were used and growth rates were expressed as the translation per day along the longitudinal axis. Asymmetrical growth was expressed as rotation of the epiphysis about the cardinal axis and/or growth rates in different regions of the growth plate. The accumulated growth was calculated according to KINEMA when 3 or more markers were inserted on one or both sides of the growth plate. If only 1 or 2 markers were inserted on each side of the growth plate, the accumulated growth could be registered as changes of distances between pairs of tantalum balls.

The post-traumatic growth pattern of supination-eversion (30 cases), supination-adduction (11 cases), and pronation injuries (9 cases) were considered separately (IV, VI, IX). Two children showed an atypical fracture pattern and 3 cases had a fracture of the distal tibial growth plate and associated tibial shaft fracture (XI).

One girl exhibited progressive growth retardation and varus tilting after a supination-adduction Stage II injury. Because of deformity, the patient was operated on with the Langenskiöld procedure. Pre-operative evaluation was performed with radiography, including tomography, roentgen

stereophotogrammetry, and scintimetry. A microscopical examination of the removed osseofibrous bridge was made. The result of the operation was evaluated clinically, radiographically, and with roentgen stereophotogrammetric analysis (VII).

One case, a patient with a comminuted fracture of the tibial shaft continuing through the ankle and the heel, was studied thoroughly (X).

The importance of different factors in predicting the post-traumatic growth pattern was evaluated with multivariate procedures (XI).

4.5 Histology (VII)

The biopsies from the removed osseofibrous bridge were decalcified, sectioned, and stained with haematoxylin-eosin (Hansson 1967).

4.6. Scintimetry (VII)

The scintimetric analysis was performed using Tc-^{99m} methylenediphosphate (Bylander et al. 1982).

4.7. Incidence (I)

From the retrospective material, children and adolescents residing in the catchment area of the University Hospital in Lund (regional material) were identified in order to calculate the annual and accumulated incidences of different fracture types. Number of patients with different injuries, their average ages, mechanism of injury, month of injury, and associated injuries were traced from the total and/or regional materials. The traumatological classification of Gerner-Smidt (1963) was compared with the anatomical classification of Salter and Harris (1963).

4.8. Statistical Methods

Student's t-test, χ^2 -test (I, II, V, VIII), Fisher's exact test (VIII), a modification of the Mantel-Haenszel (1959) test according to Miettinen (1974)(I), and multivariate procedures were used (XI).

Chapter V

RESULTS AND DISCUSSION

5.1. Incidence of Ankle and Tibiofibular Shaft Fractures (I)

In the present study the accumulated incidence, subjects 0 to 18 years of age, of tibiofibular shaft fractures was 190 and 110 per 10,000 boys and girls, respectively. The corresponding incidence of ankle fractures was slightly less in boys (172), but higher in girls (141) ($p < 0.05$). Earlier studies (Bartl 1957, Ehalt 1961, Steinert and Bennek 1966, K lle-J rgensen 1971, Feldkamp et al. 1977) suggested a dominance of tibiofibular shaft fractures.

Girls had tibiofibular shaft fracture more rarely than the boys (relative risk, girls/boys = 0.61, $p < 0.001$), mainly due to a lower frequency of transverse fractures (relative risk = 0.46, $p < 0.001$).

An associated fibular fracture occurred, on an average 5 years later than an isolated fracture of the tibia in both boys and girls as regards longitudinal fractures ($p < 0.001$), but the difference was insignificant regarding transverse fractures.

Ankle fractures occurred at a higher average age than tibiofibular shaft fractures in both boys and girls and were rather evenly distributed between the two sexes. However, boys suffered an ankle fracture at a higher average age than girls owing to different skeletal maturity.

Lauge-Hansen (1942) suggested that supination-eversion trauma to the ankle resulted in a longitudinal tibial fracture in the younger child. This was later verified by Gerner-Smidt (1963) in an experimental investigation. The present findings are consistent with earlier theories: decreasing frequency of longitudinal tibiofibular shaft fractures were found from 3 to 4 years of age in boys and from 5 to 6 years of age in girls, whereas ankle fractures due to rotational trauma showed increased incidence up to 13 to 14 years of age in boys and 11 to 12 years of age in girls. No corresponding relationship between transverse tibiofibular shaft fractures and ankle fractures due to a bending trauma was found.

This might be because transverse fractures caused by a direct trauma (traffic accidents, sports) showed an increased frequency, especially in boys from 11 to 16 years of age.

Injuries with open growth plates classified as supination-eversion and supination-adduction injuries were the most common types, but supination-eversion injuries occurred at a higher average age than supination-adduction injuries in both boys and girls ($p < 0.001$).

Pronation injuries were few, especially among girls, and constituted less than 1/8 of the ankle fractures in the regional material.

5.2. Post-traumatic Growth Pattern (IV, VI, IX, X, XI)

The post-traumatic growth pattern was separated into 5 types: symmetrical growth, initial and temporary growth stimulation, initial and temporary growth retardation, initial and progressive growth retardation, and initial and permanent growth arrest.

Symmetrical growth

Symmetrical growth during the first period of registration will continue: only a small variance may be found.

Initial and temporary growth stimulation

Growth stimulation registered during the first period can persist for about 2 to 3 years after fracture or for shorter periods and then passes into symmetrical growth or growth retardation. Asymmetrical growth within the growth region may occur.

Initial and temporary growth retardation

Growth retardation lasting at most 6 to 8 months after fracture will convert into symmetrical growth or growth stimulation.

Initial and progressive growth retardation

Retarded growth is registered on the fractured side for more than 6 to 8 months usually as asymmetrical growth within the growth region.

Initial and permanent growth arrest

No significant growth is registered on the fractured side. Thus, growth arrest during the first period will remain.

5.3. Radiographic Classification, Treatment, Post-traumatic Growth Pattern, and Long-term Prognosis

Totally, 457 ankle fractures were classified traumatologically; 363 had open growth plates, whereas 94 had closed.

In the defined population, 110 fractures of 115 of the distal fibula (96%) and 123 of 166 fractures of the distal tibia (74%) were anatomically classified according to Salter-Harris, and 269 of 283 fractures of the ankle (95%) were classified traumatologically according to Gerner-Smidt (1963).

In the total material, 130 fractures of 135 of the distal fibula (96%) and 167 of 217 of the distal tibia (77%) could be classified anatomically according to Salter-Harris. Of 363 fractures of the ankle, 346 (95%) could be classified traumatologically.

SUPINATION-EVERSION (I, II, III, IV)

Open growth plates

A. Fracture anatomy. Supination-eversion injuries with open growth plates were here classified traumatologically into 3 types: intra-articular fractures of the distal tibia (Stage I-IVa), physeal fractures of the distal fibula (Stage I/IIb₁₋₃), and extra-articular fractures of the distal tibia (Stage III-IVb).

Intra-articular fractures of the distal tibia

Stage I/IIa (Gerner-Smidt Stage I and II, Salter-Harris Type III). The first stage is a fracture of the anterolateral corner of the distal tibial epiphysis, representing detachment of the bony tibial insertion of the anterior tibiofibular ligament (Fig. 1 a). The second stage includes a periosteal detachment of the distal tibia superior to the anterior tibiofibular ligament. Radiographically, the first and second stage cannot be separated at the time of injury and were considered here as an entity. Displacement, when present, was always lateral or anterolateral.

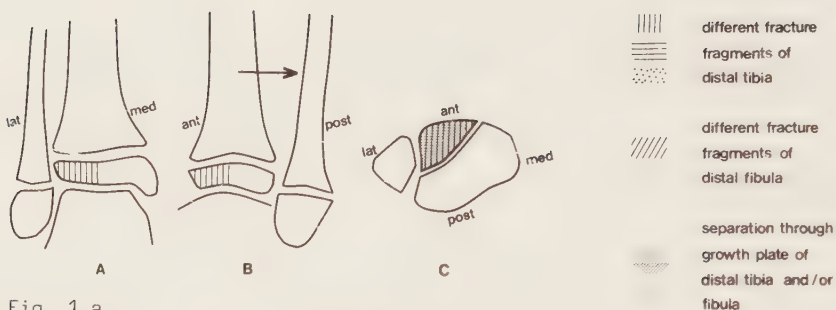


Fig. 1 a

Stage I/IIa - juvenile Tillaux fracture

A: Anteroposterior view. B: Lateral view, fibula illustrated to the right of tibia. C: Section through the growth plate of distal tibia and fibula, respectively.

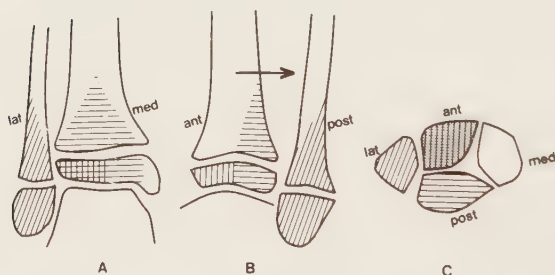


Fig. 1 b

Stage IIIa - three-fragment type without fibular fracture

Stage IVa - three-fragment type with fibular fracture

Stage IIIa (Gerner-Smidt Stage IIIa-c, Salter-Harris Type II+III+IV, or III+IV). The third stage adds a posterior meta-epiphyseal fragment yielding a fracture constituted of 3 fragments (Gerner-Smidt 1963): the first, the anterolateral part of the epiphysis, the second, the posterior part of the epiphysis with a posterior metaphyseal fragment attached to it; and the third, the anteromedial part of the epiphysis attached to the rest of the metaphysis (Fig. 1 b). However, the third and the fourth stages show a variability: the anterolateral part of the epiphysis might be attached to the posterior fragment yielding a two-fragment fracture (Fig. 1 c), indicating that the first 3 stages appear simultaneously.

Further, the anteromedial epiphyseal fragment might be detached from the metaphysis yielding another type of three-fragment fracture (Piero et al. 1981) or a four-fragment fracture (III)(Fig. 1 d). Marmor (1970) Rang (1974), Torg and Ruggiero (1975) described a further variation: the posterior epi-metaphyseal fragment was attached to the medial epiphysis, which was separated from the metaphysis in addition to the anterolateral epiphyseal fragment.

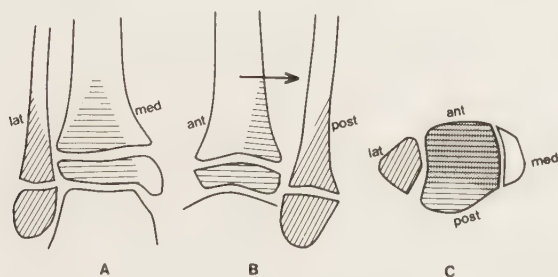


Fig. 1 c

Stage IIIa - two-fragment type without fibular fracture

Stage IVa - two-fragment type with fibular fracture

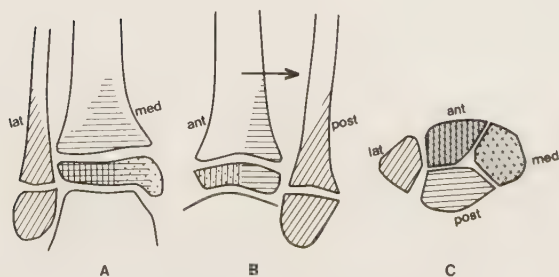


Fig. 1 d

Stage IIIa - four-fragment type without fibular fracture

Stage IVa - four-fragment with fibular fracture

Thus, the Stage IIIa fracture shows a large variability necessitating tomography or CT for a complete delineation.

Gerner-Smidt (1963) noted in experimental investigations that the Stage IIIa injury comprised three fragments. Cooperman et al. (1978) demonstrated a two-fragment fracture, as did von Laer (1981). However, von Laer (1982) could also present a three-fragment fracture according to the original description by Gerner-Smidt (1963).

Stage IVa (Gerner-Smidt Stage IVa-c, Salter-Harris Types II+III+IV, III+IV). In Stage IV a spiral or longitudinal fibular fracture is added (Fig. 1 b-1 d). Probably most Stage IV injuries show a three- or four-fragment fracture in the distal tibia (III).

The Stage III-IVa injuries may be associated with different fracture patterns of the medial malleolus. Moreover, fracture patterns similar to the adult one was observed in a few cases (II).

The variable fracture pattern of Stage III-IVa injuries makes classification according to Salter-Harris very difficult. Here, these injuries have been classified as combinations of Salter-Harris types.

Physeal fractures of distal fibula

Stage I/IIb₁ (Gerner-Smidt Stage II, Salter-Harris Type II). Lateral pressure from the talus is assumed to have detached the distal fibular epiphysis with a posterior metaphyseal fragment (Fig. 2 a). This fracture may be associated with a rupture of the anterior tibiofibular ligament.

Stage I/IIb₂ (not described by Gerner-Smidt, Salter-Harris Type III). Physeal fracture of the distal fibula with an anterior or anteromedial epiphyseal fragment, representing the fibular insertion of the anterior tibiofibular ligament. The other possibility is a physeal-epiphyseal fracture with a large posterior epiphyseal fragment (Fig. 2 b). In the present study most cases were interpreted as being the latter type (II).

Stage I/IIb₃ (not described by Gerner-Smidt, Salter-Harris classification not applicable). Fracture of the anterior or anteromedial part

 different fracture fragments of distal tibia
 different fracture fragments of distal fibula
 separation through growth plate of distal tibia and/or fibula

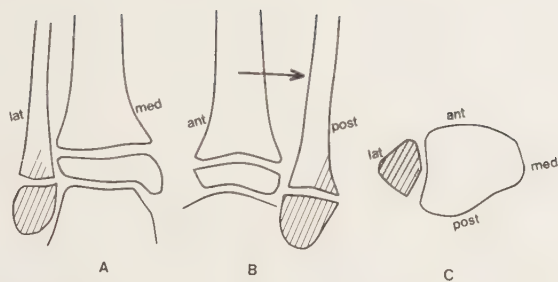


Fig. 2 a
Stage I/I Ib₁

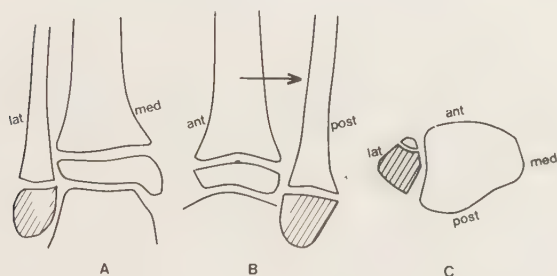


Fig. 2 b
Stage I/I Ib₂

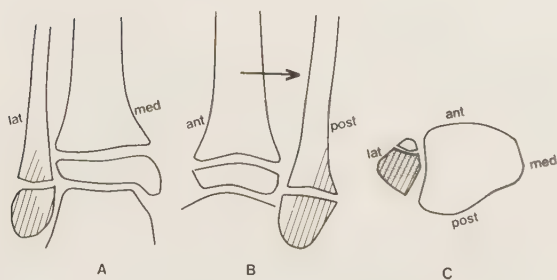


Fig. 2 c
Stage I/I Ib₃ - zigzag pattern

of the distal fibular epiphysis running upwards and laterally to the growth plate, through the growth plate for a short distance, and then upwards through the metaphysis resulting in a zigzag pattern (Z) (Fig. 2 c).

Extra-articular fracture of the distal tibia

Stage IIb (Gerner-Smidt Stage IIa-c, Salter-Harris Type II). Fracture of the distal tibial physis with a posteriorly situated metaphyseal fragment (Fig. 3). Usually, the metaphyseal fragment is localized posteromedially, but might be situated also straight posteriorly or posterolaterally. In the present material, the distal tibial fragment was displaced posteriorly or posterolaterally. In some cases, mainly the anterior part of the epiphysis had displaced somewhat laterally owing to external rotation of the distal fragment.

Stage IVb (Gerner-Smidt Stage IVa-c, Salter-Harris Type II). Similar fracture pattern as Stage IIb accompanied by a spiral or oblique fracture of the distal fibula (Fig. 3).

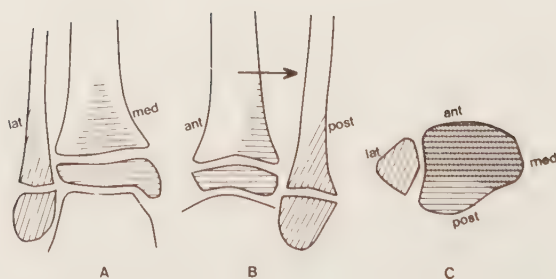


Fig. 3

Stage IIb - without fibular fracture

Stage IVb - with fibular fracture

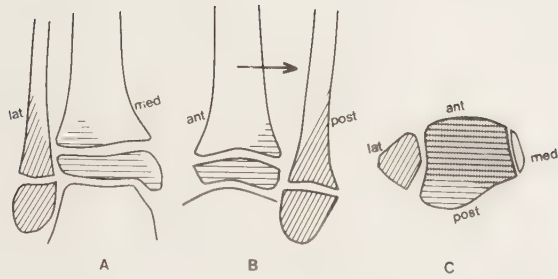


Fig. 4
 Stage IIIb - atypical without fibular fracture
 Stage IVb - atypical with fibular fracture

Atypical or unusual configurations of Stage III-IVb injuries (Salter-Harris Type II+III/IV). Two cases showed, in addition to the fracture pattern described above, also a vertical or slightly oblique fracture of the medial malleolus not entering the ankle joint but detaching a proximal and medial fragment of the epiphysis probably attached to the metaphysis (Fig. 4). A similar epiphyseal bone fragment was observed in 1 case of a Stage IIIa injury, suggesting that these fracture patterns may represent transitional types between the extra- and intra-articular fracture types of the distal tibia. Recently, von Laer (1981) demonstrated, by CT, a similar case with a fracture of the medial malleolus not entering the ankle joint, a posterior metaphyseal fragment but no additional epiphyseal fracture entering the ankle joint, which was equivalent to the Stage III-IVb injuries mentioned above.

Earlier studies have suggested different fracture mechanisms producing the injuries classified here as being due to supination-eversion. The Stage I/IIa injury was believed to be produced by adduction (Bishop 1932), lateral rotation (Kleiger and Mankin 1964), abduction or plantar flexion (Pollen 1979), or eversion lateral rotation (Letts 1982). It was suggested that the Stage I/IIb₁ injury was produced by external or lateral rotation (Bishop 1932, Kleiger and Barton 1964). The Stage I/IIb₂ and Stage I/IIb₃ injuries were not described earlier in the literature.

The Stage III-IVb injuries were classified as being due to compression (Bishop 1932), external rotation or plantar flexion (Carothers and Crenshaw 1955), lateral rotation (Kleiger and Mankin 1964), supination-external rotation or supination-plantar flexion (Diaz and Tachdjian 1978). The Stage III-IVa injuries were supposed to be produced by plantar flexion (Johnson and Fahl 1957), lateral rotation (Kleiger and Mankin 1964), axial external rotation load on a plantar flexed foot (Cooperman et al. 1978), external and plantar flexion forces (Diaz and Tachdjian 1978), or external rotation and abduction (Piero et al. 1981).

The fracture anatomy of supination-eversion injuries was demonstrated by Gerner-Smidt (1963), who showed that the above-mentioned fracture types can be summarized as injuries resulting from supination-eversion. The present study has modified Gerner-Smidt's traumatological classification by adding some additional fracture types. Moreover, Gerner-Smidt (1963) believed that rupture of the anterior tibiofibular ligament was a common feature of injuries classified here as Stage III-IVb. However, more likely traction in the anterior tibiofibular ligament produces a separation through the physis accompanied by a posterior metaphyseal fragment, but the anterior tibiofibular ligament remains intact, as suggested earlier by Kleiger and Mankin (1964), and which was found in the present study in 2 cases treated by open reduction.

An anatomical variation of the Stage III-IVa injuries was found by Gerner-Smidt (1963). Later, additional fracture patterns were demonstrated (Marmor 1970, Torg and Ruggiero 1975, Cooperman 1978, von Laer 1981, 1982, Piero et al. 1981), but these were not integrated into a traumatological entity.

The variable anatomy of supination-eversion injuries may be caused by several factors; the intra-articular fracture type occurs at a high skeletal maturity when the growth plate is thin and irregular and may sometimes be partially fused. Moreover, the force of the trauma (stage) and the extent of supination at the time of injury can also be important.

B. Sex and age distribution. The average age for boys with SE injury was higher than for girls ($p < 0.001$), and the mean age for all Stage I-IVb injuries was lower than for all Stage I-IVa injuries in both boys and girls ($p < 0.001$).

The distribution of stages between intra- and extra-articular injuries including physeal injuries of the distal fibula, was about equal. However, the Stage III injuries were more frequent than the Stage I/II and IV injuries, respectively ($p < 0.001$). Girls had more often a Stage III injury than boys, whereas boys more frequently had a Stage IV injury, and the Stage I/II injuries were rather evenly distributed ($p < 0.01$). The Stage I-IVb injuries were more common than the Stage I-IVa injuries ($p < 0.01$). However, girls had more frequently a Stage I-IVa injury and boys a Stage I-IVb injury ($p < 0.05$).

C. Treatment. Intra-articular fractures of the distal tibia proved difficult to treat by closed reduction in 7 of 10 cases where closed reduction was attempted. An additional 6 cases were treated primarily with open reduction. Thus, contrary to the findings of Cooperman et al. (1978) and Tinnemans and Severijnen (1981), closed reduction was not successful in the majority of cases in which closed reduction was attempted.

Closed reduction of Stage III-IVb injuries was performed in 19 cases; 2 cases were treated by open reduction, 1 because of periosteal interposition, and 1 upon suspicion of a rupture of the anterior tibiofibular ligament. However, in both cases, this ligament was intact. Thus, closed reduction was usually successful in cases with Stage III-IVb injuries.

D. Growth pattern and long-term prognosis. The prognosis of supination-eversion injuries concerning growth problems varies depending on the type of fracture.

The intra-articular fracture type was found to show progressive growth retardation (3 cases), growth arrest (4 cases), or no remaining growth on either side (1 case) post-traumatically. The remaining growth in cases with significant growth rates on the intact side was always low and fusion of the growth plate on the opposite side took place within a year after injury. It has been assumed previously (Rang 1974,

Spiegel et al. 1978) that the prerequisite for the Tillaux and triplane fractures is a partially closed growth plate, but in most cases studied with roentgen stereophotogrammetry, obvious but low growth rates were found on the intact side. However, late radiographic signs of arthrosis (Gerner-Smidt 1963, Beck and Engler 1969) and residual complaints such as pain (Rang 1974, Cooperman et al. 1978), stiffness (Rang 1974), and slight external rotatory deformity (Cooperman et al. 1978) have been reported. Reduction is recommended if the displacement exceeds 2 mm to prevent these problems (Cooperman et al. 1978).

The Stage I/IIb injuries showed in most cases a good prognosis. No problems are reported from isolated Salter-Harris Type II injuries in the distal fibula in the literature (Bergenfeldt 1934, Spiegel et al. 1978). Two cases with Stage I/IIb₃ injuries were studied with roentgen stereophotogrammetry and showed growth stimulation in both cases.

The extra-articular fractures of the distal tibia showed a more variable growth pattern and can appear also at a lower skeletal maturity. The Stage IIIb injuries commonly underwent growth stimulation of varying length (6 cases). Symmetrical growth or temporary growth retardation occurred in 1 case each. Growth arrest or progressive growth retardation was found in 2 cases, all with a low remaining growth. In 1 case, no growth was registered on either side.

The number of Stage IVb injuries with significant growth rates on the intact side was less; 3 showed progressive growth retardation or growth arrest. Two have been followed to skeletal maturity and developed a leg length discrepancy of the distal tibia of about 1 cm. In addition, 1 of these cases showed a progressive recurvation of the ankle of about 13°. The third case has still high growth rates on the intact side and will be followed continuously. Three additional cases showed growth stimulation in the distal tibia. In the last 3 cases no growth was registered on either side.

The treatment of displaced extra-articular supination-eversion injuries is controversial. A slight displacement of Salter-Harris Type I and II injuries especially in the younger child could, according to reports in the literature (Carothers and Crenshaw 1955, Ehlers and Eberlein 1964, Rang 1974), be accepted since the deformity will be re-

modelled during subsequent growth, whereas several authors (Titze 1967, Suessenbach and Weber 1970, Boissevain and Raaymakers 1979) stressed the importance of exact reduction in the adolescent child. Weber (1966) and Beck and Engler (1969) stressed the importance of exact reduction for normal growth. In the present study (IV) only small angular deformities were present at healing and no significant spontaneous correction was observed. Thus, exact reduction is preferable in the supination-eversion Stage III-IVb injuries, because an angular deformity of the epiphysis may persist.

C_l_o_s_e_d_g_r_o_w_t_h_p_l_a_t_e_s

Supination-eversion injuries in cases with closed growth plates occurred in girls from 13 years of age and in boys from 16 years of age. The Stage II injuries were the most common ones as reported earlier by Cedell (1967) concerning adolescents 15 to 19 years of age. In the present study, 21 of 30 cases were treated with open reduction and fixation.

SUPINATION-INVERSION (I)

Stage I. (Gerner-Smidt Stage I) Avulsion of an anterior epiphyseal fragment from the distal fibula corresponding to the attachment of the anterior talofibular ligament and, in addition, a tear in the anterolateral part of the joint capsule.

Stage II. (Gerner-Smidt Stage II) Injury to the joint capsule between the talus and the navicular bone.

Stage III. (Gerner-Smidt Stage III) Injury to the calcaneocuboid ligament.

In the present investigation only injuries of the ankle were considered excluding the Stage II and Stage III injuries. Furthermore, ligamentous injuries without bony fragments may occur in the older child and adolescent as well as detachment of the talar insertion of the anterior talofibular ligament (Lindstrand 1976) - injuries that were

not included in the present study. Finally, some of the bony injuries might have been diagnosed as distortion and were not registered.

Persisting discomfort because of defectively healed ligamentous injuries and/or calcification of displaced ligamentous attachments in children were reported by Gerner-Smidt (1963) and Danielsson (1980).

SUPINATION-ADDUCTION (I, V, VI)

Open growth plates

A. Fracture anatomy. Supination-adduction injuries were classified into 2 stages; the first stage was separated into fractures engaging the distal fibular growth plate with or without a separate epiphyseal fracture and fractures only engaging the distal fibular epiphysis.

Stage I. Physeal fracture. (Gerner-Smidt 1963 Stage I, Salter-Harris Type II, II, or III). Fracture through the distal fibular physis with or without an epi- or metaphyseal fragment (Fig. 5 a-c). This fragment is always small (height up to 2 to 3 mm) and is sometimes present on X-rays only as a small sliverlike cortical avulsion from the metaphysis or the epiphysis.

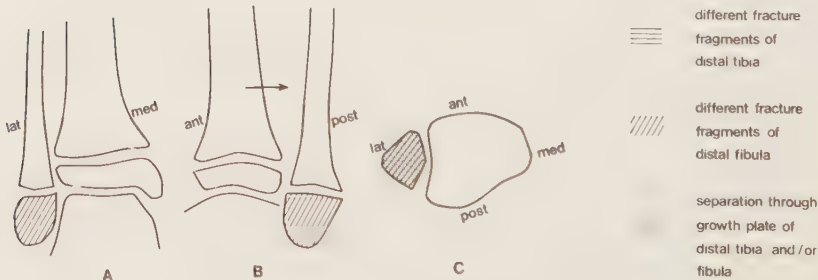


Fig. 5 a
Stage I - physeal fracture
distal fibula: Salter-Harris I

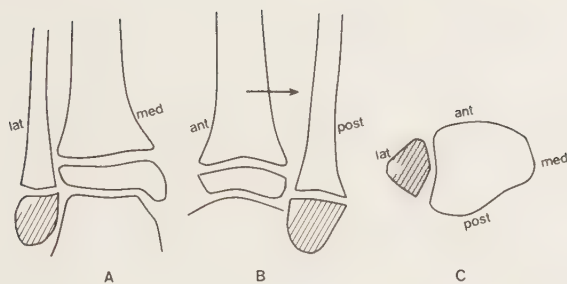


Fig. 5 b
Stage I - physeal fracture
distal fibula: Salter-Harris III

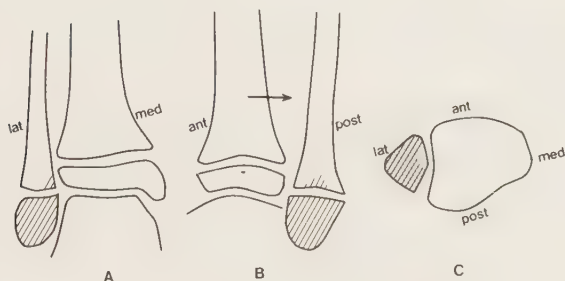


Fig. 5 c
Stage I - physeal fracture
distal fibula: Salter-Harris II

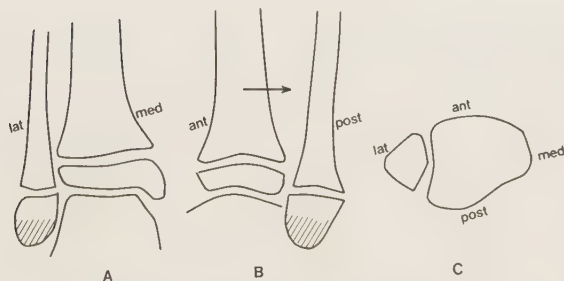


Fig. 5 d
Stage I - epiphyseal fracture

Epiphyseal fracture. (Germer-Smidt Stage I.) Fracture of the distal fibular epiphysis represented as a curved fracture when situated at the distal part of the epiphysis. When the fracture was more proximal, it usually became more transverse (Fig. 5 d).

Stage II. (Germer-Smidt Stage II, Salter-Harris Type I, II, or III through the distal fibula, Type III, IV, or zigzag pattern through the distal tibia).

In addition to the first stage, a fracture of the medial malleolus is present usually as a Salter-Harris Type III (Fig. 6a), occasionally as Type IV injury. Some of the Type IV fractures run vertically through the medial part of the epiphysis entering the growth plate, then medially through the growth plate for some millimetres, and finally upwards through the medial part of the metaphysis forming a zigzag pattern (Fig. 6 b).

When displacement was found, the medial malleolus displaced upwards and medially.

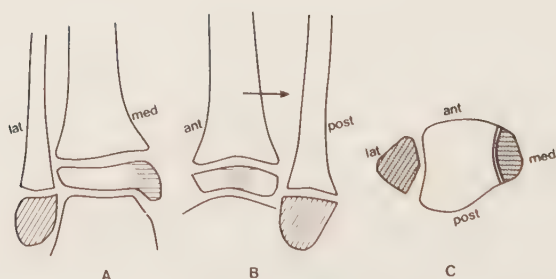


Fig. 6 a
Stage II

distal fibula: Salter-Harris I
distal tibia: Salter-Harris III

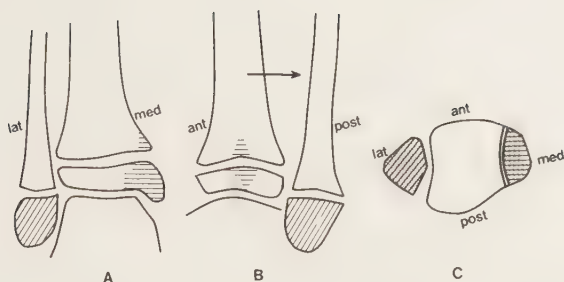


Fig. 6 b

Stage II

distal fibula: Salter-Harris I

distal tibia: Salter-Harris IV(Z)

The Type I injuries might cause diagnostic problems, but they can be revealed by a slight displacement; the tip of the lateral malleolus moves medially and lateral widening of the growth plate is found. Undisplaced fractures might be revealed radiographically 2 to 3 weeks after fracture by a thin periosteal callus at the metaphysis.

Because of diagnostic problems associated with physeal separations through the distal fibula, it is probable that the actual number of cases was somewhat higher, especially as radiographic examination was repeated in only a few cases.

B. Age and sex distribution. The average age of boys with supination-adduction injuries and open growth plates was 1 to 2 years higher than that of girls ($p < 0.05$). The average age for Stage I injuries through the distal fibular physis and for Stage II injuries was about 2 years higher for boys than for girls ($p < 0.05$), but the Stage I injuries through the distal fibular epiphysis showed the same average age (about 10 years in both sexes).

C. Treatment. No Stage I injury with open growth plate was treated with open or closed reduction.

Of 34 Stage II injuries with open growth plates, 2 were treated with closed reduction, 1 with closed reduction and percutaneous pinning, and 7 with open reduction and osteosynthesis.

D. Growth pattern and long-term prognosis. The Stage I injury has usually a good prognosis. Instability and/or pain were reported in 2 cases after osseous supination-adduction Stage I injuries by Gerner-Smidt (1963).

Post-traumatic painful calcification was reported by Danielsson (1980), but these injuries were probably of supination-inversion (supination-internal rotation) type. Premature closure of the growth plate after Stage I physeal injuries is very rare. Gerner-Smidt (1963) found 1 case. Speigel et al. (1978) reported shortening in 2 cases out of 16 re-examined Salter-Harris Type I fibular fractures. However, whether or not these injuries were associated with a fracture of the tibia was not reported, and no traumatological classification was used.

In this study roentgen stereophotogrammetric analysis of 1 case with a supination-adduction Stage I injury showed growth stimulation of the distal fibula.

Varus deformity after supination-adduction Stage II injuries was reported in several studies (McFarland 1931, Aitken 1936, Gill and Abbott 1941, Giuliani 1952, Carothers and Crenshaw 1955, von Muralt 1956, Langenskiöld 1967b, Kleiger 1974). However, Gerner-Smidt (1963) found only one case out of 40 re-examined with varus deformity. Aitken (1936) believed that about 40% of all injuries develop a deformity, whereas Giuliani (1952) believed that all supination-adduction injuries sustained at lower ages develop deformity.

Roentgen stereophotogrammetric analysis of 10 cases showed growth stimulation (2 cases), symmetrical growth (1 case), or progressive growth retardation (1 case) of the distal tibia in children under 10 years of age, whereas the older children showed symmetrical growth (2 cases), temporary growth retardation (1 case), or growth arrest (3 cases). A similar distribution as regards the post-traumatic growth pattern in the distal fibula was found; however, initial and temporary growth retardation was not registered. The age-related distribution of

the different growth patterns could be due to a more active growth region in the younger children and a better possibility to regenerate the growth cartilage in the damaged region. It is noteworthy that the Type I or Type II fibular injuries, according to Salter-Harris, manifested a similar growth pattern to the Type III and IV injuries in the distal tibia.

A 6-year old girl developed a progressive deformity after a displaced supination-adduction Stage II injury, treated by closed reduction and percutaneous pinning (VII). Because of deformity, the patient was operated on with the Langenskiöld (1967a, 1981) procedure. Pre-operative tomograms revealed a bony bridge of the growth plate surrounded by a sclerosis and an asymmetrical metaphyseal condensation line. Posteriorly, the medial malleolus was displaced 1 to 2 mm upwards forming a step in the ankle joint and growth plate, probably due to incomplete reduction, but the displacement might also be a result of the medial malleolus healing to the metaphysis and sliding upwards during growth during the first months after the trauma.

Tc^{99m}-MDP scintimetry 13 months after fracture showed reduced activity on the injured side, but no significant regional differences within the growth region of the distal tibia (Bylander et al. 1982).

Microscopical investigation of the resected osseofibrous bridge showed plexiform and irregular bone formation; on the metaphyseal side, areas with newly formed callus, small areas with fibrous tissue, and around the osseofibrous bridge a wide growth plate.

The proximal part of the osseofibrous bridge was easily uncovered during the operation suggesting a loose fibrous connection to the metaphyseal bone and no permanent bony bridge between the bony epiphysis and the metaphysis, as has been suggested earlier by Langenskiöld (1967a). The existence of an osseofibrous connection is stressed by the finding of longitudinal growth, as registered by roentgen stereophotogrammetry.

Post-operative roentgen stereophotogrammetric analysis showed that the bony epiphysis of the tibia had moved about 0.7 mm distally on the medial side and 0.25 mm on the lateral side from about 2 to 3 weeks before the operation when the previous examination was performed. Further

examinations post-operatively showed a two-step recovery; during the first 3 months the growth rate was highest medially, during the next 4 months, highest laterally; and during the latest 10 months, again a slightly higher growth rate was registered medially.

Kinema analysis showed a progressive recurvation and varus position which before the operation had reached about 11° respectively. The analysis before and immediately after the operation showed mainly a reduction of the varus position to 8° . During the first post-operative period, the varus position was reduced to about 6° , but increased during the third and fourth periods to about 9° . During the fifth period, again a decrease of the varus position to about 6° was registered. During the last period, 2 of the metaphyseal bone markers showed instability, making a correct Kinema analysis impossible. Movements about the transverse axis were small during the post-operative periods; no significant correction of the recurvation was observed.

This case demonstrates the value of the roentgen stereophotogrammetric method as regards early detection of a growth disturbance. The post-traumatic evaluation is facilitated and an eventual recurrence of the deformity will be detected early. With the present knowledge of the nature of a progressive growth retardation after physeal fracture in the younger child, an operative procedure to restore normal growth will be performed earlier when the post-traumatic growth pattern is established by the roentgen stereophotogrammetric technique.

C l o s e d g r o w t h p l a t e s

Supination-adduction injuries in adolescents with closed growth plates occurred from 15 years of age in both boys and girls. One of thirteen Stage I injuries and 4 of 6 Stage II injuries were treated with open reduction and fixation.

ADDUCTION-COMPRESSION (I)

A. Fracture anatomy. In the retrospective material of Gerner-Smidt, 1 fracture type was found that was not produced experimentally.

Stage I. (Gerner-Smidt Stage I, Salter-Harris Type I injury through the distal fibula). Physeal fractures through the distal fibula (same as supination-adduction Stage I).

Stage II. (Gerner-Smidt Stage II, Salter-Harris Type II or Types I+IV through distal tibia). In addition to the first stage physeal-metaphyseal fractures with a medial metaphyseal fragment, and also sometimes a vertical epiphyseal fracture.

This injury was classified as a third degree supination-adduction injury according to Ashhurst and Bromer (1922) and Bishop (1932). Gerner-Smidt (1963) believed that the trauma was axial compression to the ankle joint in the position of adduction. Furthermore, all fractures described by this author were spoke accidents. In the present investigation only 5 cases were found, and none showed an epiphyseal fracture. However, oblique fractures of the distal metaphysis of the tibia ending close to the growth plate and with medial displacement were rather common in the younger child.

PRONATION-EVERSION (I, VIII, IX)

O p e n g r o w t h p l a t e s =====

A. Fracture anatomy. The pronation-eversion injuries showed usually 1 characteristic fracture pattern and were not further subgrouped.

Stage I-II. (Gerner-Smidt Stage I-II, Salter-Harris Type II through the distal tibia). Fracture through the growth plate of the distal tibia (Stage I) with an anterolateral metaphyseal fragment (Stage II) (Fig. 7)

Stage III-IV. (Gerner-Smidt Stage III-IV, Salter-Harris Type II through the distal tibia). In addition to the first and second stage,

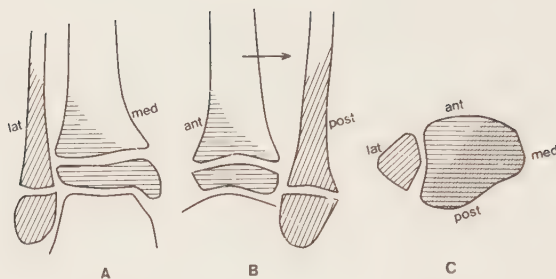


Fig. 7

Stage I-II - physeal-metaphyseal fracture of the distal tibia (Salter-Harris II)

Stage III-IV - + metaphyseal fibular fracture
posterolateral metaphyseal fragment

a spiral, oblique, or sometimes a comminuted fracture of the distal fibula at the level of or above the tip of the metaphyseal fragment in the distal tibia (Stage III). The fourth stage includes a detachment of the bony insertion of the posterior tibiofibular ligament, but a distinction between the third and fourth stage proved difficult in the present study. When displacement was found, the distal tibial epiphysis, with the anterolateral fragment, was displaced anterolaterally (Fig. 7).

Divergent fracture patterns were found in 2 cases.

B. Sex and age distribution. No statistically significant differences between average ages or distribution of stages were found.

C. Treatment. One case with a Stage I-II injury was treated with closed reduction, 14 with a Stage II-IV injury. One case showing an atypical fracture pattern was treated by open reduction and fixation.

The pronation-eversion injuries showed a high frequency of displacement in this material. These children (mainly boys) had often suffered a high-energy trauma. Moreover, the pronation-eversion Stage III-IV injuries showed the highest frequency of closed reduction of all ankle injuries. Thus, these injuries were more frequently treated with somekind of reduction than the supination-eversion and supination-adduction inju-

ries. Difficulties in achieving an exact reduction was previously reported by Gerner-Smidt (1963) and found in the present material. This might be explained by a medial periosteal interposition (Suessenbach and Weber 1970, Olerud and Reutersköld 1971, Rang 1974). Further, pronation-eversion Stage III-IV injuries showed a tendency to undergo redisplacement in the present investigation as reported in the literature (Bartl 1957, Gerner-Smidt 1963).

D. Growth pattern and long-term prognosis. Roentgen stereophotogram-metric analysis of the growth pattern after pronation-eversion injuries showed growth stimulation in the younger children (10 to 12 years of age - 3 cases) and progressive growth retardation or growth arrest in the older ones. In 1 case the growth stimulation was followed by growth retardation. Asymmetrical growth, of varying degree, was observed in all cases with growth stimulation and in 1 case with progressive growth retardation. One case showed no growth on either side.

Two patients with a valgus position of the ankle at healing showed correction of the deformity as a result of asymmetrical growth with higher growth rates laterally than medially, finally resulting in a varus position. This type of deformity after similar injuries has been reported by several authors (Bartl 1957, Gerner-Smidt 1963, Olerud and Reutersköld 1971). Carothers and Crenshaw (1955) thought this was a result of asymmetrical growth due to weight-bearing, but it is more probable that damage to the medial part of the growth plate is responsible for correction by growth. This hypothesis is supported by the findings of Farine and Spira (1968) that the physeal fracture, in areas, enters the uncalcified and reproductive part of the growth plate because of its undulated appearance in the older child.

PRONATION-ABDUCTION (I, VIII, IX)

O p e n g r o w t h p l a t e s

A. Fracture anatomy. Pronation-abduction injuries were separated into fractures mainly involving the medial and/or lateral malleolus (Stage I-II [III]a), and fractures superior to the malleolar region (Stage I-IIb).

Stage Ia. (Gerner-Smidt Ia, rarely physeal fracture of Salter-Harris Type III). Epiphyseal/physeal fracture of the medial malleolus or rupture of the deltoid ligament (Fig. 8). One out of 8 cases showed involvement of the medial part of the growth plate in the distal tibia.

Stage IIa (and IIIa). (Gerner-Smidt Stage IIa, rarely Salter-Harris Type III injury through the distal tibia. Salter-Harris Type I or II through the distal fibula). In addition to first stage fracture through the distal fibular growth plate (Fig. 8). According to Gerner-Smidt, the second stage might be represented as an epiphyseal fracture of the distal fibula or a ligamentous injury at the tip of the lateral malleolus, but these fracture types were not found in the present study. In the older child, the second stage, as in the adult, is represented as a rupture of the anterior and posterior tibiofibular ligaments, sometimes visible on radiographs as small fragments at the anterolateral and/or posterolateral corner of the distal tibial epiphysis; third fragment of Tillaux (1892). The third stage will include a transverse metaphyseal fibular fracture (Fig. 9).

Stage Ib. (Gerner-Smidt Stage Ib, Salter-Harris Type I injury through the distal tibia). Fracture through the growth plate of the distal tibia without epi- or metaphyseal fragments (Fig. 10).

Stage IIb. (Gerner-Smidt Stage IIb, Salter-Harris Type I through the distal tibia). Transverse or oblique fracture through the metaphysis of the distal fibula, in addition, to the first stage (Fig. 10). Displacement, when present, was mainly lateral.

The Stage Ib injury as the fibular injury in the pronation-abduction Stage IIa and supination-adduction Stage I-II injury when undisplaced presented difficulties in radiographic evaluation. Besides metaphyseal callus formation appearing radiographically some weeks after the injury, these fractures might be revealed by scintimetry, as demonstrated by von Walter et al. (1980).

According to this study, isolated Salter-Harris Type I injuries in the distal tibia are rare. Gerner-Smidt (1963) found only 2 cases and believed that the first and second stage were produced almost simultaneously.

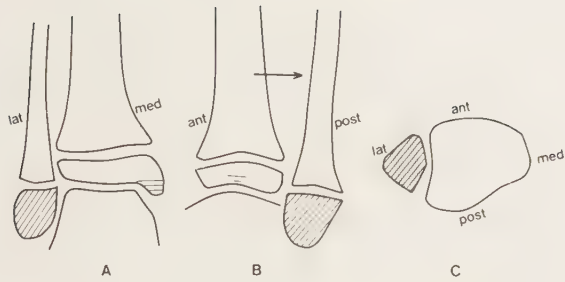


Fig. 8

Stage Ia - fracture of the medial malleolus
(rarely Salter-Harris III)

Stage IIa - + physeal fracture of the distal
fibula (Salter-Harris I or II)

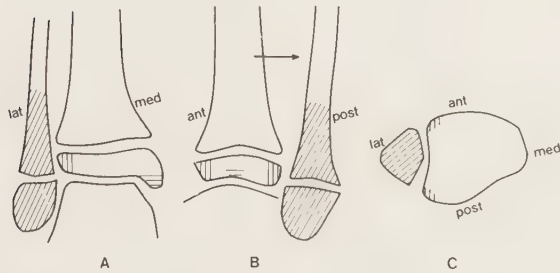


Fig. 9

Stage I - fracture of the medial malleolus

Stage II - + rupture of the anterior and posterior
tibiofibular ligaments or epiphyseal tib-
ial fractures (Salter-Harris III)

Stage III - + metaphyseal fracture of the distal
fibula

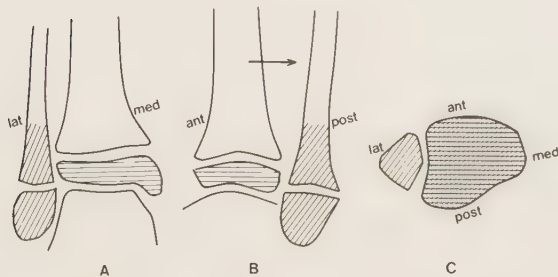


Fig. 10

Stage Ib - physeal fracture of the distal
tibia (Salter-Harris I)

Stage IIb - + metaphyseal fracture of the
distal fibula

The physeal fracture in the Stage IIb injury is more easily recognized than in the Stage Ib injury because of a more or less pronounced lateral displacement. When the displacement is small or minimal, it might be more difficult. Thus, when a transverse distal metaphyseal fibular fracture is present, a slight lateral displacement of the distal fragment might indicate physeal injury of the distal tibia. If the displacement is medial, rather suggesting a supramalleolar adduction injury, a physeal injury of Salter-Harris Type I in the distal tibia is less probable.

The Salter-Harris Type I injuries of the distal tibia in this study were all interpreted as pronation-abduction injuries. Described in the literature (Lovell 1968, Nevelös and Colton 1977, Henke and Kiple 1979) are a few cases of a Salter-Harris Type I injury through the distal tibia with the fibula fixed behind the tibia, and which is due to a rotatory trauma. In the present study, no case displayed a rotatory displacement, and it is not known whether a rotatory fracture of Salter-Harris Type I in the distal tibia without fibular injury or displacement occurs.

B. Sex and age distribution. The average age of girls with a pronation-abduction injury was less than that of boys ($p < 0.05$). The Stage Ia injury proved more common in girls than in boys, whereas the Stage IIa injury was more common in boys ($p < 0.05$).

C. Treatment. No Stage I injury was treated with reduction. Two cases with Stage IIa injuries were treated with open reduction, whereas 3 cases with Stage IIb injuries were treated with closed reduction.

D. Growth pattern and long term prognosis. Isolated fractures of the medial malleolus (Stage Ia) generally show a good prognosis. Minor problems have been reported in the literature (Ehalt 1961, Gerner-Smidt 1963). In the present study, 1 case showed persisting symptoms due to instability at follow-up 4 years after trauma.

Roentgen stereophotogrammetric analysis of 1 case with a Stage IIa injury showed symmetrical growth in the distal fibula. Gerner-Smidt (1963) reported 2 cases with arthrosis, instability, and clinical symptoms. One case in the retrospective study developed valgus deformity

after an open and displaced Stage IIa injury. Moreover, growth arrest after physeal injuries through the distal fibula, as in the Stage IIa, was seen after 2 cases of atypical fractures; both with an injury to the distal tibia and one of them with symptoms due to lateral dislocation of the talus that required operative correction of the deformity. Thus, the Stage IIa injuries may develop into arthrosis if a displaced fracture of the medial malleolus is present, and the risk of a growth disturbance in the distal fibula must be considered. Exact reduction of displaced injuries will reduce the risk for the first complication, but it will not be eliminated if a growth disturbance of the fibula causes ankle instability and/or deformity.

Roentgen stereophotogrammetric analysis of 1 case with a Stage Ib injury showed growth stimulation. The risk of growth disturbance after this injury is reported low (Salter-Harris 1963, Suessenbach and Weber 1970, Rang 1974). Spiegel et al. (1978) found 1 out of 28 re-examined cases with shortening after Salter-Harris Type I injuries through the distal tibia. Also, deformities at healing were spontaneously corrected by growth. Contrary to this, Gerner-Smidt (1963) found 3 children with valgus position of the ankle after Stage I-IIb injuries. Valgus deformity combined with a slight lengthening of the bone was found in 3 re-examined cases in the present material 3 to 10 years after Stage IIb injuries.

PRONATION-DORSALFLEXION (I, VIII)

Open growth plates

A. Fracture anatomy

Stage I-II. (Lauge-Hansen 1953 Stage II, Salter-Harris Type II). Physeal-metaphyseal fracture of the tibia with an anteriorly situated fragment (Fig. 11)

Stage III. Transverse fracture of the distal fibular metaphysis (Fig. 11).

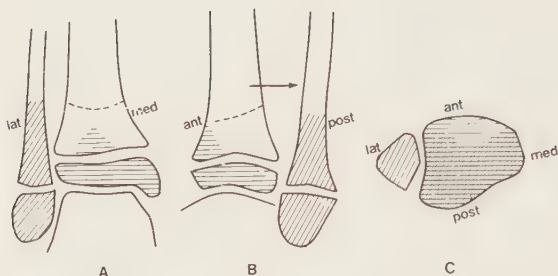


Fig. 11

- Stage I-II - physeal-metaphyseal fracture of the distal tibia (Salter-Harris II)
 Stage III - + metaphyseal fracture of the distal fibula
 (Stage IV - + transverse metaphyseal tibial fracture indicated by a dashed line)

Stage IV. Transverse fracture of the distal tibial metaphysis at the level of the tip of the metaphyseal fragment (Fig. 11).

The pronation-dorsalflexion injury is rare. Gerner-Smidt regarded these injuries to be closely related to the pronation-eversion type and found 2 injuries that were classified in this group. A variant of the pronation-dorsalflexion fracture was presented by Duran et al. (1977) showing an intra-articular fracture through the anterior part of the epiphysis and metaphysis associated with a fibular physeal injury and displacement of the distal fragments including the ankle of about 90° . This injury might be compared to the atypical intra-articular injury classified in the present material as due to pronation-eversion (VIII).

B. Treatment. In the present material the displacement was small in all cases; no reduction was performed.

Pronation injuries and closed growth plates

Pronation injuries in adolescents with closed growth plates occurred from 13 years of age in girls and from 15 years of age in boys. Sixteen injuries occurred in boys and 15 in girls. All except 5 Stage I injuries were treated with open reduction and fixation.

ATYPICAL FRACTURE PATTERN (I)

Seventeen cases with open and 8 with closed growth plates could not be classified traumatologically.

5.4. Factors of Importance in Predicting the Post-traumatic Growth Pattern After Ankle Fractures (XI)

The influence of various factors, characterizing the physeal injury and its treatment, on the post-traumatic growth pattern was evaluated with multivariate analysis. The post-traumatic growth pattern was separated into 4 groups by combining symmetrical growth and initial and temporary growth retardation into 1 group; the 3 other types of growth patterns representing their own group, or were placed into 2 groups by separating progressive growth retardation and growth arrest from the others.

The first step in multivariate analysis was to compare predictors with different groups (growth patterns) resulting in an F-value of a magnitude not influenced by other predictors. Low accuracy resulted when using 4 result variables; the predicted outcome as compared with the actual one showed only 24 out of 60 correctly classified cases.

When 2 result variables were used, the accuracy was higher. It was found that treatment, displacement, and when excluding the atypical cases, also skeletal maturity, showed a significant F-value when considered individually. Thus, cases with displacement requiring open reduction and with high skeletal maturity were likely to develop a progressive growth retardation or growth arrest. Stepwise linear discriminant analysis showed that 40 of 60 cases (39 of 55 excluding atypical cases) were correctly classified.

The discriminant function (including all cases) was

$$D = 9.65 - 0.92x_1 - 0.46x_2 - 1.52x_6 - 0.73x_7 - 1.39x_9 + 2.41x_{10},$$

where x_1 = sex, x_2 = skeletal maturity, x_6 = region of physeal fracture,

x_7 = anatomical classification, x_9 = treatment, x_{10} = associated tibial shaft fracture.

The patient is likely to show normal growth, initial and temporary growth retardation, or initial growth stimulation of varying length if the discriminant score $(D) \geq 0$. If the discriminant score is < 0 the patient is classified as likely to show a progressive growth retardation or growth arrest.

The traumatological classification was separated into several variables, such as position of foot at injury, type of trauma, stage, and to some extent site of physal fracture. This separation was necessary due to the limited number of cases, but implies that some information was not considered, e.g. intra-articular supination-eversion injuries occur at a high skeletal maturity with a low remaining growth, pronation-eversion Stage III-IV and supination-adduction Stage II injuries might show a progressive varus tilting, whereas supination-eversion injuries might show a recurvation. Furthermore, all types of injuries were not represented.

The Salter-Harris classification alone could not significantly separate the physal fractures because of a different post-traumatic growth pattern; in the discriminant function it is of some importance, but also other factors and interdependency must be considered. This finding concerning the value of the Salter-Harris classification is contradictory to previous reports (Salter 1974, Czitrom et al. 1981).

The type of treatment was of importance in separating injuries developing progressive growth retardation or growth arrest from the others. However, this variable also shows a high degree of dependency, as only displaced fractures were reduced and mainly combined tibiofibular injuries. This resulted consistently in disappearance of stage and displacement from the discriminant function. Thus, the high F-value associated with treatment might also suggest that the operative skill can be further improved, although the properties of reduced injuries might suggest damage to the growth plate at the time of injury as being determinative.

Some authors (Aitken 1965, Spiegel et al. 1978) do not believe that it is possible to restore a favourable growth by exact reduction. How-

ever, when the physeal damage is limited, a favourable prognosis may be obtained by gentle and exact reduction without damaging the growth plate during the reduction or with the osteosynthesis.

The prognostic importance of skeletal maturity may be associated with the anatomy of the growth plate and the growth potential. The younger child shows a wider and more uniform growth plate than the older child and has a large remaining growth and a higher growth rate.

Chapter VI

GENERAL SUMMARY

Earlier studies reported the relative frequency (Peterson and Peterson 1972, Ogden 1981), the fracture anatomy (Gerner-Smidt 1963, Salter 1974), and the long-term prognosis (Gerner-Smidt 1963, Spiegel et al. 1978) of ankle fractures in children. However, the incidence calculated from a defined population has not been known; the traumatological classification by Gerner-Smidt (1963) has not been further evaluated; and the applicability (Rang 1974, Bylander et al. 1981a, Peterson and Burkhart 1981) and the value of the Salter-Harris classification in predicting the post-traumatic growth pattern have been questioned (Lombardo and Harvey 1977, Bylander et al. 1981a). The anatomy of the triplane fracture has been focused on in several studies (Marmor 1970, Torg and Ruggiero 1975, Cooperman et al. 1978), but several fracture patterns were not recognized as a traumatologic entity. Earlier methods did not allow a detailed registration of the post-traumatic growth pattern after physeal fractures until the introduction of roentgen stereophotogrammetry by Selvik (1974). By using conventional methods and more recently introduced procedures, such as roentgen stereophotogrammetry, computed tomography, and Tc^{99m} -scintimetry, the present study aimed to investigate further the concept of ankle fractures in children.

Children and adolescents, aged 0 to 18 years, with fractures of the ankle and the tibiofibular shaft were studied by collecting data from the case records regarding age, sex, date of injury, mechanism of injury, treatment, and from re-examination of the fracture anatomy from radiographs. Totally, there were 462 fractures of the tibiofibular shaft in 450 patients and 457 ankle fractures in 453 patients.

Ankle fractures with open growth plates were traumatologically classified according to Gerner-Smidt (1963) and anatomically according to Salter and Harris (1963). Ankle fractures with closed growth plates were classified according to Lauge-Hansen (1942, 1953). The classifications were slightly modified in order to further adapt them for clinical use. Two fracture types involving the distal fibular physis and classified as supination-eversion (SE) Stage I/Ib₂ and I/Ib₃ could not be found

in the previous literature. Furthermore, triplane fractures associated with different fracture types of the medial malleolus were not earlier described.

From a defined population, the incidence of different fracture types was calculated. The accumulated incidence, children and adolescents 0 to 18 years of age, of tibiofibular shaft fractures was 190 and 110 per 10,000 boys and girls, respectively, whereas the accumulated incidence of ankle fractures was slightly lower (172) in boys, but higher (141) in girls.

Ankle fractures occurred at a higher mean age than tibiofibular shaft fractures. Injuries classified as SE and supination-adduction (SA) were found to be the most common types, but SE injuries occurred at a higher mean age than SA injuries in both boys and girls.

It was suggested that rotational trauma to the lower leg results in a longitudinal fracture of the tibiofibular shaft in the younger child and in an ankle fracture in the older child. No corresponding relationship between transverse tibiofibular shaft fractures and ankle fractures due to bending could be found.

A comparison between the traumatological classification of Gerner-Smidt and the anatomical classification of Salter and Harris showed that the traumatological classification failed to classify 5% of the injuries in a defined population, whereas the anatomical classification failed to classify 17%.

Five cases of intra-articular SE injuries (Tillaux and triplane fractures) were examined with computed tomography and 2 of these also with conventional tomography. With these methods the metaphyseal and the epiphyseal fracture anatomy and the fracture relation to the joint area could be studied in detail. Three two-fragment fractures and 1 three-fragment fracture were revealed, but the three-fragment fracture proved to comprise 4 fragments at operation.

This part of the investigation demonstrated similarities between the Tillaux and the different types of triplane fractures and added 2 new types of the previously known types.

The post-traumatic growth pattern was prospectively studied with roentgen stereophotogrammetry in 55 children with ankle fractures involving the growth plates of the distal tibia and/or fibula. Thirty cases were classified as SE fractures, 11 SA, 7 pronation-eversion (PE), 2 pronation-abduction (PA), 2 atypical, and 3 as physeal fractures of the distal tibia with an associated diaphyseal fracture, 1 of which also had a triplane ankle fracture.

Five types of growth pattern were observed: symmetrical growth, initial growth stimulation of varying length, initial and temporary growth retardation, initial and progressive growth retardation, and initial and permanent growth arrest.

Asymmetrical growth within the growth plate was found especially associated with progressive growth retardation and growth stimulation.

The growth rate could be determined within 3 months after fracture. The type of growth disturbance could be determined about 6 months after fracture.

The importance of different factors in predicting the future growth was evaluated using multivariate statistical analysis.

Predicting of a specific growth pattern out of 4 types could be performed only with a low accuracy. Separation of the growth patterns into 2 groups with symmetrical growth, initial and temporary retardation, and growth stimulation in 1, and progressive growth retardation and growth arrest in another resulted in a higher accuracy. Comparing the predicted outcome with the actual and misclassified outcomes resulted in 2 out of 3 fractures being correctly classified concerning future growth. Considered independently, treatment, displacement, and skeletal maturity were found of some importance to separate cases with different growth patterns.

One case with an ankle fracture of SA type manifested progressive growth retardation and varus tilting of the ankle post-traumatically. The patient was operated on with the Langenskiöld procedure. Pre-operative evaluation was performed with radiography including tomography, roentgen stereophotogrammetry, and scintimetry. The morphology of the

removed osseofibrous bridge was studied. Early post-operative evaluation was performed with roentgen stereophotogrammetry and showed a two-step recovery. The first recovery was observed during the initial period and the second one started at about 6 months after the operation.

On the basis of the present knowledge of the nature of a progressive growth retardation after a physeal fracture in a young child, an operative procedure in order to restore normal growth should be performed early.

In summary, it was found that the traumatological classification facilitates the identification of different fracture types and reduction by providing information about the genetic production. The anatomical classification according to Salter-Harris, when applicable, adds further information about the relation of the fracture line to the growth plate and the joint. When predicting the future growth, other factors such as sex, skeletal maturity, displacement, and type of reduction must be considered. However, the limited accuracy in predicting the post-traumatic growth pattern after ankle fractures in children indicates that in most cases there is indication for follow-up in order to detect growth disturbances.

Chapter VII

CONCLUSIONS

Retrospective material:

1. The accumulated incidence, patients 0 to 18 years of age, of tibiofibular shaft fractures was 190 and 110 per 10,000 boys and girls, respectively, whereas the accumulated incidence of ankle fractures was slightly less (172) in boys but higher (141) in girls. Ankle fractures occurred at a higher age than tibiofibular shaft fractures. It was suggested that rotational trauma to the lower leg results in a longitudinal fracture of the tibiofibular shaft in the younger child and in an ankle fracture in the older child. No corresponding relation between transverse tibiofibular shaft and ankle fractures due to bending could be found.
2. The radiographical anatomy of ankle fractures in children could usually be identified from conventional radiograms including 4 standard views (AP, lateral, 20° internal rotation, 55° external rotation), but was difficult concerning intra-articular SE (Stage III-IVa) injuries. Two types of physeal fractures through the distal fibula classified as SE Stage I/Ib₂, and I/Ib₃, and different fracture types of the medial malleolus combined with a triplane fracture were not earlier described. Moreover, adult fracture pattern in cases with open growth plates and physeal fractures with associated tibiofibular shaft fractures were found in a few cases. The different types of ankle fractures showed specific sex and age distribution. The SE and SA injuries were most frequent.
3. The traumatological classification by Gerner-Smidt failed to classify 14 cases (5%), whereas 48 (17%) of the physeal fractures could not be classified according to Salter and Harris in a defined population.
4. Displaced intra-articular SE injuries were difficult to treat by closed reduction, whereas extra-articular SE injuries were not. SA Stage II injuries were usually treated by open reduction; unfavourable results were observed after some cases treated by closed reduction and/or remaining

displacement after reduction. PE injuries showed the highest frequency of reduction; redisplacement after reduction was observed and was believed to be caused by medial periosteal interposition. PA Stage IIa injuries of transitional type were, when displaced, treated by open reduction to restore joint congruity at the medial malleolus and the anatomy of tibiofibular attachments, which might be difficult with closed reduction. PA Stage IIb injuries, when displaced, were treated by closed reduction.

Prospective material:

1. The intra-articular SE injuries showed a complex fracture pattern, necessitating tomography and/or CT for a detailed delineation. However, an undisplaced physal fracture might only be revealed by surgery.
2. The growth rate after fractures through the growth plate of the distal tibia and/or fibula could be registered within 3 months after fracture and the type of growth pattern could be established 6 to 8 months after fracture. Five types of growth patterns were observed: symmetrical growth, initial and temporary growth stimulation of varying length, initial and temporary retardation, initial and progressive growth retardation, and initial and permanent growth arrest. Asymmetrical growth within the growth region was mainly registered in cases with progressive growth retardation and in some cases with growth stimulation. Symmetrical growth was registered only in a few cases. Thus, physal fractures of the distal tibia and/or fibula result in growth disturbance of varying type and degree, depending on skeletal maturity, displacement, and treatment.
3. It was possible to predict the future growth pattern with an accuracy of 2 out of 3 cases correctly classified when dividing the 5 growth patterns into 2 groups. Considered individually, treatment, displacement, and skeletal maturity were most important. Knowledge of the traumatological classification adds some further information, e.g. some injuries occur at high skeletal maturity with low remaining growth, different types of asymmetrical growth may be associated with variable trauma types. Ankle fractures involving both the distal tibia and the fibula requiring open reduction because of displacement were found to be likely to undergo progressive growth retardation or growth arrest.

The Salter-Harris classification provides information about the relation of the fracture line to the growth plate and the joint, but the value of this classification in predicting the post-traumatic growth pattern should not be overestimated.

The limited accuracy in predicting post-traumatic growth pattern after ankle fractures in children indicated that in many cases there are indications for radiographic follow-up to detect growth disturbance. Using roentgen stereophotogrammetry, it is possible to register growth disturbance before deformity has developed.

4. A two-step recovery after the Langenskiöld operative procedure was found; the first was observed immediately after the operation and probably being caused by detachment of a medial binding caused by an osseofibrous bridge. The second was observed from about 6 months after the operation and was interpreted as an effect of regeneration of the medial part of the growth plate. With the present knowledge of the nature of progressive growth retardation after a physeal fracture in the younger child, an operative procedure to restore growth will be performed earlier when the post-traumatic growth pattern can be established by the roentgen stereophotogrammetric technique. Thus, the roentgen stereophotogrammetric method provides guidelines for the treatment of growth deformity, facilitates the post-operative evaluation, and detects early an eventual recurrence of the deformity.

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